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PAPER

Body composition estimates from NHANES III bioelectrical impedance data

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BACKGROUND: Body composition estimates for the US population are important in order to analyze trends in obesity, sarcopenia and other weight-related health conditions. National body composition estimates have not previously been available.
OBJECTIVE: To use transformed bioelectrical impedance analysis (BIA) data in sex-specific, multicomponent model-derived prediction formulae, to estimate total body water (TBW), fat-free mass (FFM), total body fat (TBF), and percentage body fat (%BF) using a nationally representative sample of the US population.
DESIGN: Anthropometric and BIA data were from the third National Health and Nutrition Examination Survey (NHANES III; 1988 – 1994). Sex-specific BIA prediction equations developed for this study were applied to the NHANES data, and mean values for TBW, FFM, TBF and %BF were estimated for selected age, sex and racial-ethnic groups.
RESULTS: Among the non-Hispanic white, non-Hispanic black, and Mexican-American participants aged 12 – 80 y examined in NHANES III, 15 912 had data available for weight, stature and BIA resistance measures. Males had higher mean TBW and FFM than did females, regardless of age or racial-ethnic status. Mean TBW and FFM increased from the adolescent years to mid-adulthood and declined in older adult age groups. Females had higher mean TBF and %BF estimates than males at each age group. Mean TBF also increased with older age groups to approximately 60 y of age after which it decreased.
CONCLUSIONS: These mean body composition estimates for TBW, FFM, TBF and %BF based upon NHANES III BIA data provide a descriptive reference for non-Hispanic whites, non-Hispanic blacks and Mexican Americans in the US population.
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Keywords: body composition; obesity; BIA; NHANES; health surveys

Introduction

Overweight and obesity are increasing in the US population.[1,2] Excess adiposity is the major weight-related health concern up to the seventh decade of life, but an increased lifespan[3] indicates the importance of lean tissue loss and its association with frailty and sarcopenia in the elderly.[4,5] Fat and lean components of the body including total body fat (TBF), fat-free mass (FFM), and total body water (TBW) are important constituents that link obesity, aging, and chronic disease with subsequent morbidity and mortality.[6–8] There exists little accurate information at present on estimates of TBW, FFM, TBF, and percentage fat (%BF) for the US population as a whole.[9–11] Systems capable of reliably quantifying body composition under controlled conditions, such as bioelectrical impedance analysis (BIA) and dual-energy X-ray absorptiometry (DXA), have been introduced and subsequently validated over the past two decades.[12,13] This technology and the increasing clinical and research importance of body composition highlight the need for improved information on population estimates of TBW, FFM, TBF and %BF.

Prior surveys and studies of body composition in the US population are based largely on anthropometric data including measures of body weight, stature, skinfold thick-

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nesses and circumferences. These provide correlates of fatness (ie body mass index; BMI) or approximate estimates of regional and total body fatness. These data for the US population collected over the past 30 y have a limited ability to quantify body composition. The report of the 1994 NIH-sponsored Technology Assessment Conference, 'Bioelectrical Impedance Analysis in Body Composition Measurement',[14] recommended that national reference distributions for body composition be developed using BIA data from the Third National Health and Nutrition Examination Survey.[15] BIA systems are calibrated for the population under study by developing prediction formulae based on criterion methods from resistance, stature and other easily acquired variables.[16–20] Most of these predictive equations are based on limited samples and two-component models that describe fat and FFM only.[21] To use the NHANES III BIA data to estimate national body composition distributions, a set of externally derived BIA prediction equations were developed using isotope dilution to predict TBW and a multicomponent model to predict FFM.[22] These equations provided estimates for the major body compartments when applied to the NHANES III data for non-Hispanic whites, non-Hispanic blacks and Mexican-Americans aged 12–80 y. This report fulfills the recommendation of the 1994 NIH Conference[14] with the presentation of cross-sectional estimates for mean TBW, FFM, TBF and %BF by sex and age for these three racial-ethnic groups in the US population.

Methods

Sample

The NHANES III was a nationally representative, two-phase, 6 y, cross-sectional survey conducted from 1988 until 1994.[15] The complex sampling plan used a stratified, multistage, probability cluster design. The initial sampling of households, identification of participants, and the collection of data in mobile examination centers in NHANES III were similar to that in previous NHANES.[15] An individual's racial-ethnic status was self-identified.

The total NHANES III sample consisted of 31 311 examined participants. Children younger than 12 y of age and pregnant women were not eligible for the BIA procedure in NHANES III. There were also very few participants over 80 y of age. After excluding 12 562 participants with ages <12 y or >80 y, 798 participants with race-ethnicity other than non-Hispanic white, non-Hispanic black or Mexican American and 2039 participants missing weight, stature and/or BIA resistance, the available analytic sample contained 15 912 participants. The developed BIA prediction equations[22] were applied to this sub-sample, but additional exclusions were made when predicted TBW exceeded 80% of body weight ($n=1$), or when the calculated TBF was negative ($n=8$). These last exclusions resulted in a final sample of 15 903 participants, 2880 non-Hispanic white males, 3277 non-Hispanic white females, 2348 non-Hispanic black males, 2606 non-Hispanic black females, 2494 Mexican American males, and 2298 Mexican American females, for development of the body composition distribution data.

Measurements

Documentation for the NHANES III procedures includes written descriptions[15] and a video demonstration.[23] Body weight was measured with an electronic load cell scale to the nearest 0.01 kg. Participants wore only under-shorts and disposable paper shirts, pants and foam slippers but no adjustment was made for this minimal clothing weight (0.18 kg) in the analyses. Stature was measured to the nearest 0.1 cm using a fixed stadiometer. Participants were positioned with heels, buttocks, back and head against the upright surface of the stadiometer with the head positioned in the Frankfort horizontal plane.

Participants had a single, tetrapolar BIA measurement of resistance (Res) and reactance at 50 kHz taken between the right wrist and ankle while in a supine position, using Valhalla 1990B Bio-Resistance Body Composition Analyzer (Valhalla Scientific, San Diego, CA, USA).[24] the decision regarding the selection of the impedance analyzer was made *ca* 1986. The reactance values were not used in the body composition prediction equations[22] and, therefore, are not presented or discussed further. The measurement accuracy of the Valhalla impedance machines used in NHANES III was independently certified by the National Institute of Standards and Technology following the survey.

Body composition calculations

Conversion of NHANES III BIA values. The TBW and FFM prediction equations[22] used Res data from RJL bioelectrical impedance analyzers (RJL, Clinton Twp, MI, USA). The NHANES III BIA data were obtained with a Valhalla impedance analyzer. However, all BIA resistance data reported in this manuscript are converted RJL Res values because there are no prediction equations from large-scale studies using Valhalla bioimpedance instruments. Before applying the TBW and FFM prediction equations to these data, the Valhalla Res value for each NHANES III subject was converted to an equivalent RJL Res value using equations developed from a separate, independent sample. Details of this conversion process are presented in the Appendix.

Prediction equations. The TBW and FFM, BIA prediction equations listed below[22] were applied to the respective NHANES III anthropometric and converted BIA resistance data for each selected NHANES III participant to derive estimates for TBW and FFM. The converted NHANES III, RJL resistance values were used to calculated the impedance index of stature squared divided by resistance (S^2/Res) in the TBW and FFM prediction equations.

$$\text{Males}\quad TBW = 1.203 + 0.176\ \text{weight} + 0.449\ S^2/\text{Res}\quad r^2 = 0.84,\ \text{RMSE} = 3.81$$

$$\text{Females}\quad TBW = 3.747 + 0.113\ \text{weight} + 0.45\ S^2/\text{Res}\quad r^2 = 0.79,\ \text{RMSE} = 2.61$$

$$\text{Males}\quad FFM = -10.678 + 0.262\ \text{weight} + 0.652\ S^2/\text{Res} + 0.015\ \text{Res}\quad r^2 = 0.90,\ \text{RMSE} = 3.9\ \text{kg}$$

$$\text{Females}\quad FFM = -9.529 + 0.168\ \text{weight} + 0.696\ S^2/\text{Res} + 0.016\ \text{Res}\quad r^2 = 0.83,\ \text{RMSE} = 2.9\ \text{kg}$$

Estimates for TBF and %BF for each NHANES III participant were derived from their corresponding estimated FFM using the equations TBF = weight − FFM and %BF = TBF/weight.

Statistical methods

Descriptive statistics including means, standard deviations and standard errors for estimates of TBW, FFM, TBF and %BF were calculated for defined age, sex and racial-ethnic groups. The age groups were defined at 2 y intervals from 12 to 20 y of age and at 10 y intervals thereafter. These means were also presented graphically with the values plotted at the middle of each age group. The mean values for TBW, FFM, TBF and %BF were estimated using SAS[25] and include the appropriate survey sampling weights to produce representative estimates for selected groups in the civilian, non-institutionalized population of the US. The sample weights account for sampling variability and adjust the data for differential probability of selection of persons in the NHANES III complex sample survey design.

Variance estimation. The means presented in this report are based on data collected from a complex sample design, and techniques that account for this design were used to estimate the standard errors of these means (ie the square root of their variance). Variance estimates based on the complex sample design are different from and generally larger than those obtained under the assumption of simple random sampling. SUDAAN, a statistical software package that incorporates the sample weights and accounts for the complex sample design through Taylor Series linearization was used to estimate the design effects.[26] Details of the variance estimation process are found in the Appendix.

Results

Tests of statistical significance were not performed because the results for several of the variables are calculated estimates, and the objective of this paper was to present descriptive information only. A qualitative review of these findings suggests that differences among the groups conform to findings from other large and small-scale studies. Means for weight, stature, BMI, Res and S^2/Res are shown in Tables 1–3. Estimated means for TBW, FFM, TBF, and %BF are shown in Tables 4–7 and Figures 1–4, and they are summarized in the following text.

Anthropometry and BIA

The number of participants in NHANES III available to construct the body composition distributions by age, sex and racial-ethnic groups are presented in Tables 1–3 along with descriptive statistics for the measured and calculated independent variables. As expected, across racial-ethnic groups at ages ≥ 14 y, mean statures and weights were larger for males than females. Within each race-ethnic group for males and females, mean weights and BMIs increased almost consistently up to age 60 y and decreased afterwards. The BMI means were larger among non-Hispanic black and Mexican-American females than non-Hispanic white females at almost all ages, but especially in the adults. Non-Hispanic black adult females had the largest mean BMI values. Among the adult males, the BMI means were approximately equal to most ages.

The females had larger mean estimates for Res than the males. Means estimates for S^2/Res were larger for males than the females at all ages. This is consistent with an expected greater fluid volume associated with a greater FFM among males.

The Res means for non-Hispanic white females exceeded those of non-Hispanic black females at all but one age group. The non-Hispanic white females also had larger Res means than the Mexican-American females at all but two of the younger age groups. There was no consistent pattern between the non-Hispanic black and Mexican-American females in Res means as they varied by age groups. However, mean estimates for S^2/Res for non-Hispanic black females were consistently larger than those of non-Hispanic white females at all but one age group, and both these groups of females had mean estimates larger than those of Mexican-American females at all age groups.

The non-Hispanic black males had larger Res means than the non-Hispanic white males at all ages, but Res means varied between the non-Hispanic black and Mexican-American males by age groups. This variation by age groups also existed for mean Res values between the non-Hispanic white and Mexican-American males. Mean estimates for S^2/Res for non-Hispanic white males were consistently larger than those of non-Hispanic black males at all but one age group, and both these groups of males had larger mean estimates than those of Mexican-American males at all age groups.

Comparative distributions of body compartments

Total body water and fat-free mass. As shown in Tables 4 and 5 and Figures 1 and 2, the means for TBW and FFM within racial-ethnic groups had similar patterns across age groups. Among males, the estimated TBW and FFM means

Table 1 Selected anthropometric and impedance measures according to age and sex for non-Hispanic white people: NHANES III (Res and S^2/Res computed with RJL-Valhalla conversion factor)

		Non-Hispanic white males				*Non-Hispanic white females*			
Age groups	*Measurements*	n	*Mean*	*s.d.*	*s.e.*	n	*Mean*	*s.d.*	*s.e.*
12–13.9 y	Weight (kg)	88	51.7	12.3	1.5	101	52.1	13.3	1.6
	Stature (cm)	88	159.6	8.4	0.9	101	157.8	8.2	1.0
	BMI (kg/m^2)	88	20.1	3.5	0.4	101	20.9	4.7	0.6
	Res (ohms)	88	559.9	77.7	10.8	101	603.4	70.9	10.2
	S^2/Res (cm^2/ohms)	88	46.8	9.9	1.3	101	41.9	6.6	1.0
14–15.9 y	Weight (kg)	82	68.3	20.5	2.5	120	57.8	10.5	1.2
	Stature (cm)	82	172.2	7.6	0.8	120	162.6	6.0	0.7
	BMI (kg/m^2)	82	23.0	6.3	0.8	120	21.9	3.8	0.4
	Res (ohms)	82	494.2	60.1	8.7	120	616.1	75.0	10.0
	S^2/Res (cm^2/ohms)	82	60.9	8.8	1.2	120	43.6	6.3	0.8
16–17.9 y	Weight (kg)	96	70.9	13.8	1.6	104	61.1	14.5	1.7
	Stature (cm)	96	177.0	7.9	0.8	104	164.5	6.6	0.8
	BMI (kg/m^2)	96	22.6	4.0	0.5	104	22.5	4.9	0.6
	Res (ohms)	96	486.5	61.1	8.2	104	616.7	74.6	10.6
	S^2/Res (cm^2/ohms)	96	65.4	9.4	1.2	104	44.6	6.3	0.9
18–19.9 y	Weight (kg)	76	73.1	15.0	1.9	90	63.7	15.0	1.9
	Stature (cm)	76	176.9	6.7	0.8	90	164.9	5.8	0.7
	BMI (kg/m^2)	76	23.3	4.2	0.6	90	23.4	5.5	0.7
	Res (ohms)	76	489.5	52.7	7.9	90	592.0	70.9	10.8
	S^2/Res (cm^2/ohms)	76	64.7	8.1	1.2	90	46.6	6.2	0.9
20–29.9 y	Weight (kg)	384	79.2	16.6	0.9	426	63.2	14.3	0.8
	Stature (cm)	384	177.5	6.7	0.3	426	163.6	6.7	0.4
	BMI (kg/m^2)	384	25.1	4.9	0.3	426	23.6	5.1	0.3
	Res (ohms)	384	473.4	59.4	4.0	426	587.6	77.2	5.5
	S^2/Res (cm^2/ohms)	384	67.7	9.9	0.6	426	46.4	7.1	0.5
30–39.9 y	Weight (kg)	436	84.0	17.1	0.9	543	69.1	18.0	0.9
	Stature (cm)	436	177.8	6.8	0.3	543	164.6	6.3	0.3
	BMI (kg/m^2)	436	26.5	4.6	0.3	543	25.5	6.5	0.3
	Res (ohms)	436	463.8	60.4	3.8	543	567.2	74.1	4.7
	S^2/Res (cm^2/ohms)	436	69.5	11.3	0.7	543	48.7	7.7	0.5
40–49.9 y	Weight (kg)	410	86.0	17.0	0.9	454	70.7	16.8	1.0
	Stature (cm)	410	177.3	6.7	0.3	454	163.4	6.1	0.3
	BMI (kg/m^2)	410	27.3	4.9	0.3	454	26.6	6.5	0.4
	Res (ohms)	410	455.9	62.4	4.1	454	569.4	83.5	5.7
	S^2/Res (cm^2/ohms)	410	70.4	11.5	0.7	454	48.0	7.9	0.5
50–59.9 y	Weight (kg)	396	86.9	15.0	0.8	454	73.9	17.4	1.0
	Stature (cm)	396	176.7	6.2	0.3	454	162.4	6.0	0.3
	BMI (kg/m^2)	396	27.8	4.6	0.3	454	28.0	6.4	0.4
	Res (ohms)	396	453.6	60.7	4.0	454	559.0	80.5	5.5
	S^2/Res (cm^2/ohms)	396	70.1	9.9	0.6	454	48.2	7.6	0.5
60–69.9 y	Weight (kg)	465	84.9	14.7	0.8	447	70.3	15.1	0.9
	Stature (cm)	465	175.3	6.3	0.3	447	160.8	6.1	0.4
	BMI (kg/m^2)	465	27.6	4.2	0.2	447	27.2	5.6	0.3
	Res (ohms)	465	467.3	63.4	3.9	447	572.6	84.3	5.8
	S^2/Res (cm^2/ohms)	465	67.0	9.9	0.6	447	46.2	7.6	0.5
70–79.9 y	Weight (kg)	447	79.3	13.3	0.7	538	67.1	14.5	0.8
	Stature (cm)	447	172.4	6.7	0.3	538	158.3	6.8	0.4
	BMI (kg/m^2)	447	26.7	4.0	0.2	538	26.7	5.3	0.3
	Res (ohms)	447	470.8	62.6	3.9	538	567.9	82.1	5.2
	S^2/Res (cm^2/ohms)	447	64.3	9.9	0.6	538	45.2	8.0	0.5

increased during adolescence in all racial-ethnic groups. A progressive, but lesser increase in the adult male age groups followed until about age 60 y, after which the estimated means for TBW and FFM decreased. Females in all racial-ethnic groups had comparatively lower estimates for mean TBW and FFM than males. Among females, the increase from 13 to 19 y of age was not as pronounced as it was in males. Estimated means for TBW and FFM for females gradually increased across age groups until age 45–55 y after which they decreased for both.

Among males, estimated TBW and FFM means were generally larger for non-Hispanic whites than non-Hispanic

Table 2 Selected anthropometric and impedance measures according to age and sex for non-Hispanic black people: NHANES III (Res and S^2/Res computed with RJL-Valhalla conversion factor)

		Non-Hispanic black males				*Non-Hispanic black females*			
Age groups	*Measurements*	*n*	*Mean*	*s.d.*	*s.e.*	*n*	*Mean*	*s.d.*	*s.e.*
12–13.9 y	Weight (kg)	124	52.1	16.7	1.5	156	55.1	13.3	1.2
	Stature (cm)	124	157.9	10.1	1.0	156	159.6	7.3	0.7
	BMI (kg/m^2)	124	20.7	5.2	0.5	156	21.5	4.4	0.4
	Res (ohms)	124	568.1	75.2	8.6	156	601.1	74.7	8.6
	S^2/Res (cm^2/ohms)	124	45.2	10.2	1.1	156	43.1	6.3	0.7
14–15.9 y	Weight (kg)	131	64.4	15.4	1.4	102	62.0	16.3	1.8
	Stature (cm)	131	171.5	7.7	0.8	102	163.1	7.1	0.8
	BMI (kg/m^2)	131	21.8	4.7	0.4	102	23.2	5.3	0.6
	Res (ohms)	131	511.2	67.3	7.5	102	608.8	90.9	12.8
	S^2/Res (cm^2/ohms)	131	58.8	10.0	1.1	102	44.8	8.3	1.1
16–17.9 y	Weight (kg)	126	68.7	14.5	1.3	126	64.0	15.8	1.6
	Stature (cm)	126	173.8	7.2	0.7	126	163.9	7.0	0.7
	BMI (kg/m^2)	126	22.7	4.1	0.4	126	23.8	5.7	0.6
	Res (ohms)	126	493.3	58.3	6.6	126	611.4	72.4	9.2
	S^2/Res (cm^2/ohms)	126	62.3	9.9	1.1	126	44.6	6.3	0.8
18–19.9 y	Weight (kg)	118	74.7	16.4	1.5	110	65.8	18.6	2.0
	Stature (cm)	118	176.6	7.2	0.7	110	163.6	6.3	0.7
	BMI (kg/m^2)	118	23.8	4.4	0.4	110	24.6	6.7	0.8
	Res (ohms)	118	480.8	61.0	7.1	110	610.9	91.2	12.4
	S^2/Res (cm^2/ohms)	118	66.2	11.0	1.2	110	44.9	8.2	1.1
20–29.9 y	Weight (kg)	462	82.9	20.5	1.0	510	70.4	16.7	0.8
	Stature (cm)	462	177.1	7.4	0.4	510	163.7	6.1	0.3
	BMI (kg/m^2)	462	26.3	5.8	0.3	510	26.2	6.0	0.3
	Res (ohms)	462	474.4	63.7	3.8	510	582.5	80.6	5.1
	S^2/Res (cm^2/ohms)	462	67.5	11.3	0.7	510	47.0	7.5	0.5
30–39.9 y	Weight (kg)	454	82.9	17.9	0.9	569	76.7	20.2	1.0
	Stature (cm)	454	177.2	6.6	0.3	569	163.7	6.7	0.3
	BMI (kg/m^2)	454	26.4	5.4	0.3	569	28.6	7.4	0.4
	Res (ohms)	454	470.4	68.0	4.1	569	561.1	81.4	4.9
	S^2/Res (cm^2/ohms)	454	68.3	11.4	0.7	569	48.9	8.6	0.5
40–49.9 y	Weight (kg)	339	83.6	17.2	1.0	395	81.5	21.1	1.2
	Stature (cm)	339	176.5	7.3	0.4	395	164.2	6.1	0.4
	BMI (kg/m^2)	339	26.8	4.8	0.3	395	30.2	7.4	0.4
	Res (ohms)	339	472.6	63.6	4.4	395	544.8	85.8	6.2
	S^2/Res (cm^2/ohms)	339	67.3	11.0	0.7	395	50.7	8.6	0.6
50–59.9 y	Weight (kg)	191	83.7	19.4	1.4	231	80.7	19.4	1.5
	Stature (cm)	191	175.2	6.6	0.5	231	162.5	5.8	0.5
	BMI (kg/m^2)	191	27.2	5.7	0.4	231	30.6	7.1	0.6
	Res (ohms)	191	472.8	77.5	7.1	231	547.8	92.7	8.7
	S^2/Res (cm^2/ohms)	191	66.8	12.4	1.1	231	49.6	8.7	0.8
60–69.9 y	Weight (kg)	258	80.9	16.2	1.0	258	77.6	18.3	1.3
	Stature (cm)	258	173.6	6.6	0.5	258	161.1	6.3	0.5
	BMI (kg/m^2)	258	26.8	4.9	0.3	258	29.9	7.0	0.5
	Res (ohms)	258	476.3	78.8	6.3	258	557.7	94.3	8.4
	S^2/Res (cm^2/ohms)	258	65.1	11.9	0.9	258	47.8	8.4	0.7
70–79.9 y	Weight (kg)	145	77.0	15.5	1.3	149	74.0	16.5	1.5
	Stature (cm)	145	171.6	7.1	0.7	149	159.4	5.7	0.6
	BMI (kg/m^2)	145	26.2	4.8	0.4	149	29.1	6.3	0.6
	Res (ohms)	145	477.8	74.6	7.9	149	551.0	89.9	10.5
	S^2/Res (cm^2/ohms)	145	63.2	11.4	1.2	149	47.4	8.4	0.9

blacks and then Mexican-Americans (Figures 1 and 2). For females, estimated mean TBW and FFM values were larger for non-Hispanic blacks than non-Hispanic whites and then Mexican-Americans. The TBW and FFM means for non-Hispanic black males declined at an earlier age compared with the means for non-Hispanic white and Mexican-American males (Figures 1 and 2).

The standard deviations at all the age groups for TBW were ~6–7 l for non-Hispanic white and Mexican-American males and ~7–8 l for non-Hispanic black males. For the females,

Table 3 Selected anthropometric and impedance measures according to age and sex for Mexican-American people: NHANES III (Res and S^2/Res computed with RJL-Valhalla conversion factor)

		Mexican-American males				*Mexican-American females*			
Age groups	*Measurements*	n	*Mean*	*s.d.*	*s.e.*	n	*Mean*	*s.d.*	*s.e.*
12–13.9 y	Weight (kg)	132	52.7	14.1	1.5	139	53.3	12.3	1.2
	Stature (cm)	132	156.0	9.2	0.9	139	155.4	6.5	0.7
	BMI (kg/m^2)	132	21.4	4.6	0.5	139	21.9	4.5	0.5
	Res (ohms)	132	568.4	73.2	9.2	139	608.6	78.9	9.5
	S^2/Res (cm^2/ohms)	132	44.0	9.3	1.1	139	40.5	6.5	0.8
14–15.9 y	Weight (kg)	108	62.5	16.6	1.9	113	56.2	10.7	1.2
	Stature (cm)	108	167.2	8.5	0.9	113	157.7	6.0	0.7
	BMI (kg/m^2)	108	22.2	5.1	0.6	113	22.5	3.7	0.4
	Res (ohms)	108	510.5	61.2	8.5	113	631.4	68.8	9.2
	S^2/Res (cm^2/ohms)	108	55.9	9.8	1.3	113	40.0	5.9	0.8
16–17.9 y	Weight (kg)	126	67.9	12.2	1.3	112	62.2	15.5	1.7
	Stature (cm)	126	170.5	6.7	0.7	112	159.3	5.8	0.7
	BMI (kg/m^2)	126	23.3	3.7	0.4	112	24.5	5.7	0.7
	Res (ohms)	126	501.0	58.7	7.6	112	600.2	79.8	10.7
	S^2/Res (cm^2/ohms)	126	58.9	8.2	1.0	112	43.1	6.8	0.9
18–19.9 y	Weight (kg)	109	72.8	13.9	1.6	90	59.6	13.1	1.6
	Stature (cm)	109	171.9	6.3	0.7	90	157.7	5.7	0.7
	BMI (kg/m^2)	109	24.6	4.4	0.5	90	23.9	4.9	0.6
	Res (ohms)	109	491.2	63.0	8.7	90	614.3	67.8	10.1
	S^2/Res (cm^2/ohms)	109	61.2	8.6	1.2	90	41.0	5.5	0.8
20–29.9 y	Weight (kg)	631	73.9	13.9	0.7	509	64.8	14.5	0.8
	Stature (cm)	631	170.0	6.4	0.3	509	157.6	6.2	0.3
	BMI (kg/m^2)	631	25.6	4.2	0.2	509	26.1	5.5	0.3
	Res (ohms)	631	480.0	59.9	3.5	509	586.4	79.6	5.1
	S^2/Res (cm^2/ohms)	631	61.0	9.1	0.5	509	43.1	6.6	0.4
30–39.9 y	Weight (kg)	443	78.4	14.2	0.8	451	70.6	17.1	1.0
	Stature (cm)	443	170.6	7.0	0.4	451	156.9	6.3	0.4
	BMI (kg/m^2)	443	26.9	4.3	0.2	451	28.6	6.4	0.4
	Res (ohms)	443	469.7	59.8	4.1	451	554.1	76.4	5.2
	S^2/Res (cm^2/ohms)	443	63.1	9.9	0.7	451	45.3	7.2	0.5
40–49.9 y	Weight (kg)	361	82.0	14.5	0.9	334	73.4	13.9	0.9
	Stature (cm)	361	169.7	6.3	0.4	334	157.2	5.4	0.4
	BMI (kg/m^2)	361	28.4	4.4	0.3	334	29.7	5.6	0.4
	Res (ohms)	361	453.0	58.5	4.5	334	549.1	75.6	5.9
	S^2/Res (cm^2/ohms)	361	64.7	9.8	0.7	334	45.8	6.6	0.5
50–59.9 y	Weight (kg)	165	82.6	15.1	1.4	171	71.3	13.7	1.2
	Stature (cm)	165	169.3	6.0	0.5	171	155.7	5.4	0.5
	BMI (kg/m^2)	165	28.7	4.5	0.4	171	29.5	5.5	0.5
	Res (ohms)	165	449.3	62.7	7.1	171	549.0	81.0	8.8
	S^2/Res (cm^2/ohms)	165	65.1	10.7	1.2	171	45.1	7.0	0.7
60–69.9 y	Weight (kg)	301	78.2	12.7	0.9	278	70.0	14.1	1.0
	Stature (cm)	301	168.3	6.0	0.4	278	154.3	5.9	0.4
	BMI (kg/m^2)	301	27.6	4.0	0.3	278	29.5	5.9	0.4
	Res (ohms)	301	469.3	63.9	5.4	278	548.1	78.5	6.7
	S^2/Res (cm^2/ohms)	301	61.5	9.1	0.7	278	44.4	7.3	0.6
70–79.9 y	Weight (kg)	118	72.3	12.5	1.4	101	65.0	13.0	1.5
	Stature (cm)	118	165.5	5.7	0.6	101	153.0	5.9	0.7
	BMI (kg/m^2)	118	26.3	4.0	0.4	101	27.8	5.5	0.7
	Res (ohms)	118	486.1	68.8	9.1	101	568.8	80.2	11.4
	S^2/Res (cm^2/ohms)	118	57.6	9.6	1.2	101	42.1	7.1	1.0

the standard deviations were $\sim$4–5 l for non-Hispanic white and Mexican-American females and $\sim$5–6 l for non-Hispanic black females. This same pattern of larger standard deviations in non-Hispanic blacks also occurred for FFM, but here the standard deviations for non-Hispanic whites were larger than those of the Mexican-Americans. The standard deviations at all the age groups for FFM were $\sim$9–10 kg for non-Hispanic white males, $\sim$8–9 kg for Mexican-American males and $\sim$9–11 kg for non-Hispanic black males. For the females, the standard deviations were $\sim$5–6 kg for non-Hispanic white females $\sim$5–6 kg for Mexican-American females and $\sim$5–8 kg for non-Hispanic black females.

Table 4 Total body water (l) according to age, sex and ethnicity: NHANES III

	Non-Hispanic white			*Non-Hispanic black*			*Mexican-American*		
Age (y)	*Mean*	*s.d.*	*s.e.*	*Mean*	*s.d.*	*s.e.*	*Mean*	*s.d.*	*s.e.*
Males									
12–13.9	31.3	6.3	0.8	30.7	7.0	0.7	30.2	6.2	0.7
14–15.9	40.6	7.0	0.9	38.9	6.7	0.7	37.2	6.9	0.9
16–17.9	43.1	6.2	0.8	41.2	6.6	0.7	39.6	5.5	0.6
18–19.9	43.2	5.8	0.8	44.1	7.5	0.8	41.5	5.9	0.7
20–29.9	45.5	6.9	0.4	46.1	8.0	0.4	41.6	6.1	0.3
30–39.9	47.2	7.6	0.4	46.5	7.7	0.4	43.4	6.5	0.4
40–49.9	48.0	7.8	0.5	46.1	7.5	0.5	44.7	6.6	0.5
50–59.9	47.9	6.5	0.4	45.9	8.5	0.7	45.0	7.1	0.7
60–69.9	46.2	6.6	0.4	44.7	7.7	0.5	42.6	5.9	0.4
70–79.9	44.0	6.4	0.4	43.2	7.4	0.7	39.9	6.3	0.7
Females									
12–13.9	28.5	4.2	0.6	29.3	4.1	0.4	27.9	4.2	0.5
14–15.9	29.9	3.7	0.5	30.9	5.3	0.7	28.1	3.7	0.4
16–17.9	30.7	4.0	0.5	31.0	4.2	0.5	30.2	4.5	0.6
18–19.9	31.9	4.2	0.6	31.4	5.5	0.7	28..9	3.7	0.5
20–29.9	31.8	4.5	0.3	32.8	4.9	0.3	30.5	4.3	0.2
30–39.9	33.5	5.1	0.3	34.4	5.8	0.3	32.2	4.8	0.3
40–49.9	33.3	5.2	0.3	35.8	6.0	0.4	32.6	4.3	0.3
50–59.9	33.8	5.1	0.3	35.2	5.8	0.5	32.1	4.4	0.4
60–69.9	32.5	4.8	0.3	34.0	5.6	0.4	31.6	4.6	0.4
70–79.9	31.6	4.9	0.3	33.4	5.3	0.6	30.1	4.4	0.6

Total body fat and percentage body fat. As presented in Tables 6 and 7 and Figures 3 and 4, females had larger estimated TBF and %BF means than males at all ages. Across racial-ethnic groups, TBF means for males did not shown any appreciable differences. In contrast, estimates for TBF means were largest for non-Hispanic black females, followed by Mexican-American and then non-Hispanic white females. Plots of these TBF means by sex, race and the selected age groups are presented in Figure 3. Between 13 and 19 y of age, Mexican-American males tended to have larger TBF means than non-Hispanic white and black males, after which these differences were small except for 25 y of age.

Table 5 Fat-free mass (kg) according to age, sex and ethnicity: NHANES III

	Non-Hispanic white			*Non-Hispanic black*			*Mexican-American*		
Age (y)	*Mean*	*s.d.*	*s.e.*	*Mean*	*s.d.*	*s.e.*	*Mean*	*s.d.*	*s.e.*
Males									
12–13.9	41.8	8.2	1.0	40.9	9.3	0.9	40.3	8.2	0.9
14–15.9	54.3	9.6	1.2	52.2	9.0	0.9	49.8	9.3	1.2
16–17.9	57.8	8.4	1.0	55.3	8.9	0.9	53.0	7.5	0.9
18–19.9	58.0	8.0	1.1	59.2	10.2	1.0	55.7	8.0	1.0
20–29.9	61.3	9.5	0.6	62.2	11.1	0.6	55.7	8.3	0.4
30–39.9	63.6	10.5	0.6	62.6	10.5	0.5	58.1	8.9	0.5
40–49.9	64.6	10.6	0.6	62.2	10.3	0.6	59.8	8.9	0.6
50–59.9	64.6	8.8	0.5	61.9	11.5	0.9	60.2	9.6	1.0
60–69.9	62.3	8.9	0.5	60.1	10.3	0.7	57.0	7.9	0.6
70–79.9	59.1	8.6	0.5	58.0	10.0	0.9	53.1	8.3	1.0
Females									
12–13.9	38.1	5.6	0.7	39.3	5.5	0.5	37.3	5.3	0.6
14–15.9	40.4	4.8	0.6	41.8	7.0	0.9	37.8	4.8	0.6
16–17.9	41.6	5.5	0.7	42.0	5.6	0.6	40.5	6.0	0.7
18–19.9	43.1	5.6	0.8	42.6	7.1	0.8	38.8	4.9	0.7
20–29.9	42.8	5.9	0.4	44.3	6.5	0.4	40.8	5.6	0.3
30–39.9	45.0	6.9	0.4	46.4	7.8	0.4	42.8	6.4	0.4
40–49.9	44.8	6.9	0.4	48.2	7.9	0.5	43.5	5.5	0.4
50–59.9	45.4	6.7	0.4	47.3	7.6	0.6	42.6	5.8	0.6
60–69.9	43.6	6.3	0.4	45.7	7.3	0.6	41.9	6.0	0.5
70–79.9	42.3	6.5	0.4	44.7	6.8	0.7	39.8	5.6	0.7

Table 6 Total body fat (kg) according to age, sex and ethnicity: NHANES III

	Non-Hispanic white			*Non-Hispanic black*			*Mexican-American*		
Age (y)	*Mean*	*s.d.*	*s.e.*	*Mean*	*s.d.*	*s.e.*	*Mean*	*s.d.*	*s.e.*
Males									
12–13.9	10.0	6.0	0.7	11.2	9.1	0.9	12.3	7.5	0.8
14–15.9	14.0	12.2	1.6	12.2	8.4	0.9	12.6	8.9	1.1
16–17.9	13.1	7.5	0.9	13.4	7.3	0.8	14.9	6.1	0.7
18–19.9	15.1	8.5	1.1	15.5	7.9	0.8	17.1	7.2	0.9
20–29.9	17.9	8.7	0.5	20.7	11.4	0.6	18.3	7.3	0.4
30–39.9	20.4	8.5	0.5	20.3	9.5	0.5	20.3	7.1	0.4
40–49.9	21.3	8.5	0.5	21.4	8.7	0.6	22.2	7.3	0.5
50–59.9	22.3	8.3	0.5	21.8	9.7	0.8	22.4	7.1	0.7
60–69.9	22.7	7.7	0.4	20.7	8.3	0.6	21.2	6.7	0.5
70–79.9	20.3	6.8	0.4	19.3	7.7	0.7	19.2	5.8	0.7
Females									
12–13.9	14.0	8.7	1.0	15.8	8.7	0.8	16.0	7.6	0.8
14–15.9	17.4	6.9	0.8	20.2	10.1	1.1	18.4	6.9	0.8
16–17.9	19.5	10.1	1.2	22.0	11.4	1.1	21.6	10.3	1.2
18–19.9	20.6	10.3	1.3	23.2	12.6	1.3	20.7	8.9	1.1
20–29.9	20.5	9.6	0.6	26.0	11.3	0.6	24.1	9.8	0.5
30–39.9	24.1	12.3	0.6	30.4	13.5	0.6	27.8	11.5	0.6
40–49.9	25.9	10.9	0.6	33.3	14.1	0.8	29.9	9.4	0.6
50–59.9	28.6	11.6	0.7	33.4	12.9	1.0	28.7	9.0	0.8
60–69.9	26.7	9.9	0.6	31.9	12.1	0.8	28.1	9.3	0.7
70–79.9	24.8	9.3	0.5	29.3	10.8	1.0	25.2	8.8	1.0

Non-Hispanic black females had larger TBF means than Mexican-American and non-Hispanic white females at almost all ages, and this difference was greater after 25 y of age. At the same time, Mexican-American females also had larger TBF means than non-Hispanic white females at most ages. In the plots for all age groups, mean TBF increased consistently for all males and females with each older age category until about 55–65 y of age. Afterwards, there was a consistent decline in TBF means in both sexes.

Estimates for mean %BF were slightly larger for Mexican-American males than for non-Hispanic white or non-Hispanic black males where estimates for mean %BF were

Table 7 Percentage body fat according to age, sex and ethnicity: NHANES III

	Non-Hispanic white			*Non-Hispanic black*			*Mexican-American*		
Age (y)	*Mean*	*s.d.*	*s.e.*	*Mean*	*s.d.*	*s.e.*	*Mean*	*s.d.*	*s.e.*
Males									
12–13.9	18.4	7.3	1.0	19.5	8.9	1.1	22.0	8.2	1.0
14–15.9	18.4	8.3	1.2	17.8	7.5	9.0	18.8	7.7	1.1
16–17.9	17.7	6.8	0.9	18.6	6.4	0.8	21.3	5.4	0.7
18–19.9	19.6	6.9	1.0	19.9	6.0	0.8	22.7	5.7	0.8
20–29.9	21.8	6.2	0.4	23.7	7.0	0.4	24.1	6.0	0.4
30–39.9	23.6	5.8	0.4	23.6	6.7	0.4	25.4	5.4	0.4
40–49.9	24.2	5.7	0.4	24.9	6.1	0.5	26.6	5.3	0.4
50–59.9	25.1	6.0	0.4	25.1	6.7	0.7	26.7	5.3	0.6
60–69.9	26.2	5.5	0.3	24.9	6.6	0.6	26.7	5.2	0.4
70–79.9	25.1	5.5	0.3	24.3	6.3	0.7	26.1	5.2	0.7
Females									
12–13.9	24.8	9.7	1.2	26.9	8.8	0.8	28.6	7.6	0.8
14–15.9	29.1	6.5	0.8	30.9	8.0	0.9	31.8	6.3	0.7
16–17.9	30.7	6.9	0.9	32.6	8.5	0.9	33.3	7.1	0.8
18–19.9	30.8	7.9	1.0	33.3	8.7	1.0	33.5	6.8	0.9
20–29.9	31.0	7.5	0.5	35.5	7.5	0.4	35.8	7.0	0.4
30–39.9	33.0	8.5	0.5	38.0	7.7	0.4	38.0	7.1	0.4
40–49.9	35.4	6.9	0.4	39.4	7.0	0.4	39.9	5.5	0.4
50–59.9	37.3	7.1	0.4	40.0	7.5	0.6	39.4	5.7	0.5
60–69.9	36.9	6.9	0.4	39.8	6.9	0.5	39.4	5.7	0.4
70–79.9	35.9	6.9	0.4	38.5	6.7	0.6	37.8	6.8	0.8

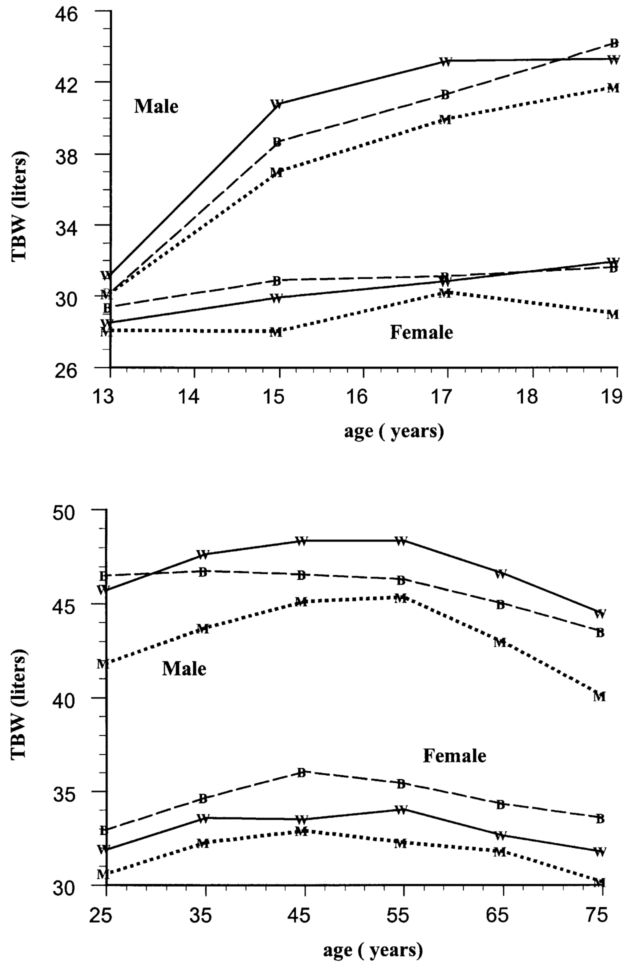

Figure 1 Estimated means for total body water (TBW) by 2 y age groups from 12 to 20 y and by 10 y age groups from 20 to 80 y for non-Hispanic white (W), non-Hispanic black (B) and Mexican-American (M) males and females.

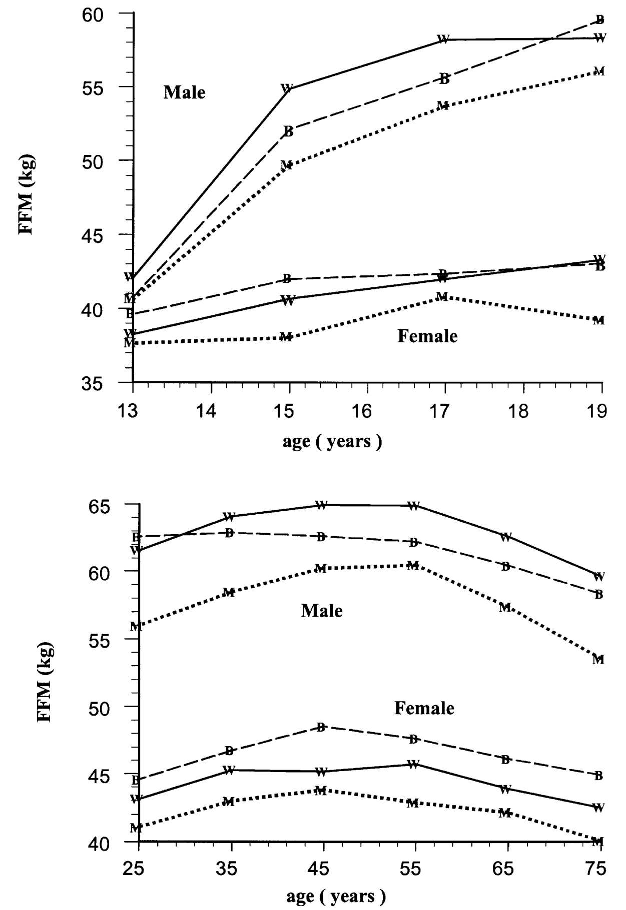

Figure 2 Estimated means for fat-free mass (FFM) by 2 y age groups from 12 to 20 y and by 10 y age groups from 20 to 80 y for non-Hispanic white (W), non-Hispanic black (B) and Mexican-American (M) males and females.

quite similar across age groups. However, estimated %BF means were noticeably similar across adult ages for non-Hispanic black and Mexican-American females. Non-Hispanic whites had the lowest estimated %BF means at all ages. Plots of these %BF means by sex, race and the selected age groups are presented in Figure 4. The %BF means reflect to some degree the sex, ethnic and age patterns for TBF. These sex differences were greatest for non-Hispanic blacks then Mexican-Americans and non-Hispanic whites. At the 25 y age category, the mean %BF for males was about 21–23%, but in females the means were 30–35%. At the 13 y age group, girls were on average as fat as males would ever get.

Between 13 and 19 y of age, Mexican-American males had larger %BF means than non-Hispanic white and black males at all ages. At most other ages, there were small differences between non-Hispanic black and white males in %BF means. Between 13 and 19 y of age, Mexican-American females had larger %BF means than non-Hispanic black and white females and non-Hispanic black females had larger means than non-Hispanic white females. After the 19 y age group, there were small differences in %BF means between Mexican-American and non-Hispanic black females, both of which were larger than the %BF means for non-Hispanic white females. For all race groups, mean %BF increases with each older age category until about 55–65 y of age. Afterwards, %BF means declined, but this decline was not as steep as it was for TBF means at the same ages. The exception was for males between 13 and 19 y where %BF means decreased and then increased for Mexican-Americans or remained approximately stable for non-Hispanic white and black males. Between the 13 and 55 y age groups, mean %BF for males increased about 5–7 percentage points, while in females the corresponding increase was about 11–13 percentage points.

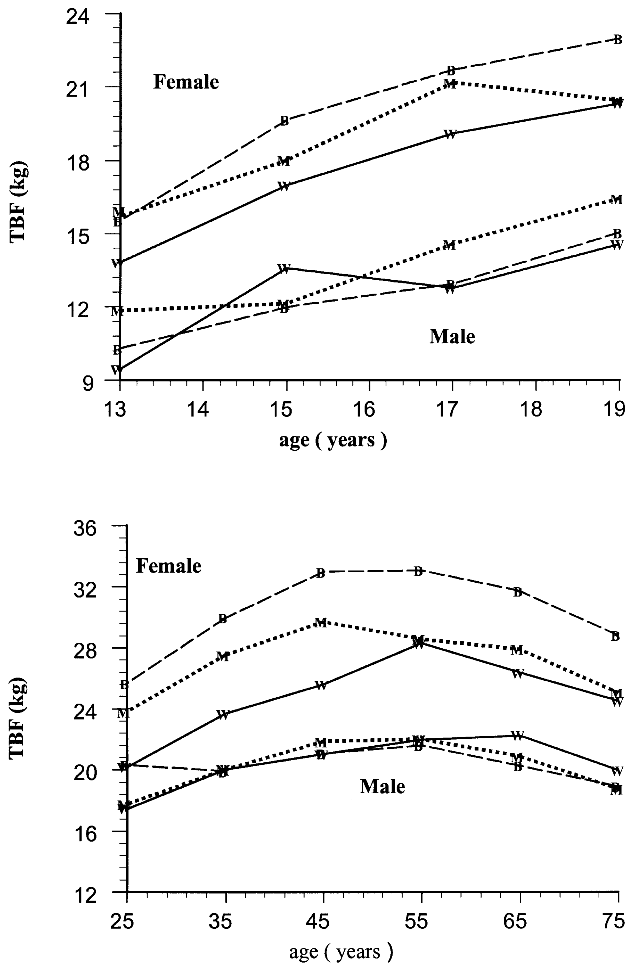

Figure 3 Estimated means for total body fat (TBF) by 2 y age groups from 12 to 20 y and by 10 y age groups from 20 to 80 y for non-Hispanic white (W), non-Hispanic black (B) and Mexican-American (M) males and females.

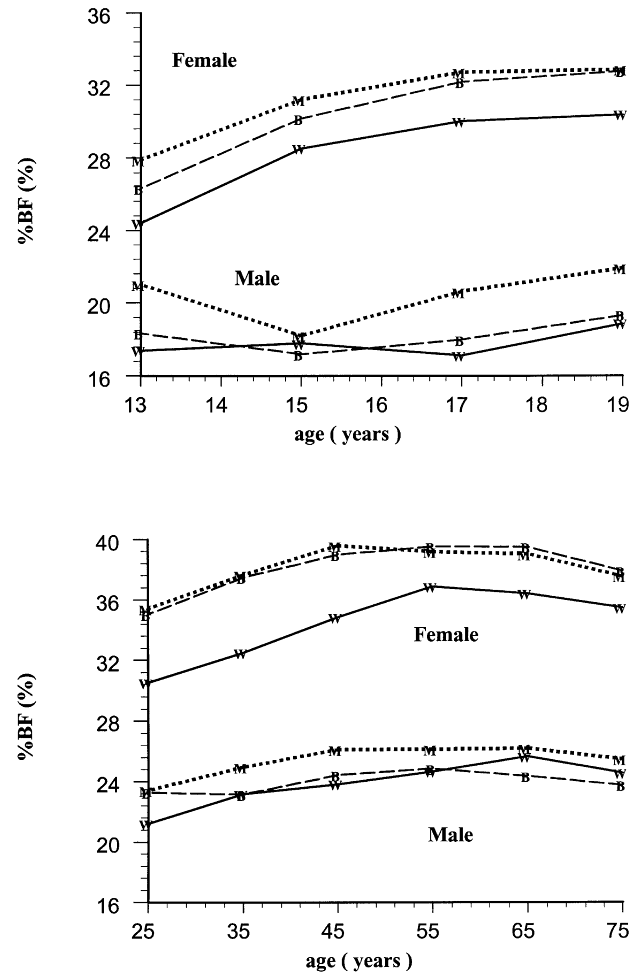

Figure 4 Estimated means for percentage body fat (%BF) by 2 y age groups from 12 to 20 y and 10 y age groups from 20 to 80 y for non-Hispanic white (W), non-Hispanic black (B) and Mexican-American (M) males and females.

Standard deviations for TBF were ~6–8 kg for non-Hispanic white males, ~5–6 kg for Mexican-American males and ~7–9 kg for non-Hispanic black males. For the females, the standard deviations were ~8–11 kg for non-Hispanic white females, ~8–10 kg for Mexican-American females and ~10–14 kg for non-Hispanic black females. This same pattern of larger standard deviations in non-Hispanic blacks again occurred for %BF, but here the standard deviations for non-Hispanic whites were larger than those of the Mexican-Americans. The standard deviations at all the age groups for %BF were ~5–7% for non-Hispanic white males, ~5–6% for Mexican-American males and ~6–7% for non-Hispanic black males. For the females, the standard deviations were ~7–8% for non-Hispanic white females ~5–7% for Mexican-American females and ~7–8% for non-Hispanic black females.

Discussion

The application of the selected equations[22] to the NHANES III BIA data presents for the first time estimates of national distributions for TBW, FFM, TBF and %BF for non-Hispanic whites and blacks and Mexican-Americans from 12 to 80 y of age. The selected equations are the most accurate and precise available for predicting TBW and FFM, and they are reasonably generalizable for individuals with body composition values at the extremes of the distribution.[22]

The patterns of the means for TBW, FFM, TBF and %BF across the age groups reflect expected associations with age and sex. These patterns with age demonstrate sex differences in the growth of these body constituents or the changes that occur during adulthood with the aging process. The large means for TBF and %BF reflect the high prevalence of obesity that has been reported previously using the NHANES III BMI data.[1,2]

Body composition distributions

Similar to other reports, males in this study generally have a larger estimated mean TBW and FFM than females, who have larger estimated TBF and %BF means than males.[27,28] The estimated means values from ages 12–20 y demonstrate the sex and age relationships with body composition that occur during adolescent growth.[29] Mean TBF increases during adolescence, but the effects of the relatively greater accretion of FFM in males than females result in a decline in estimated mean %BF for males around 14–16 y of age. Mean TBF increases through adulthood. There is also an increase in mean FFM through much of adulthood but a decline is observed at the oldest age groups.[30] These are not serial data, so the contrast between means at adjacent age groups may reflect actual trends in the changes in these body composition estimates or, alternatively, differences between the samples comprising the several age groups.

Overall, the racial-ethnic differences between non-Hispanic white and non-Hispanic black females conform to previously reported differences for smaller samples. Non-Hispanic black females had slightly larger mean values for TBW, FFM, TBF and/or %BF than non-Hispanic white females,[9,28,31–34] even though the prediction equations tended to under-estimate TBW and FFM in non-Hispanic blacks.[22] Similar comparisons with Mexican-American females are very limited.[28,34] Reported ethnic differences in body composition between non-Hispanic white and non-Hispanic black adult males differ from the present findings. Others report that non-Hispanic black males have larger amounts of TBW than non-Hispanic white males.[31,35] Similar differences in FFM or its equivalent between non-Hispanic whites and non-Hispanic blacks have been reported by Ellis,[28,34] but several other investigators have not found such differences to be statistically significant.[9,36] Comparisons with Mexican-American males have been few.[28,34] Except for possible differences in bone mineral, racial-ethnic differences in these means for TBW, FFM, and TBF at an age or across age are not clear at a population level. A reason for this lack of clarity is insufficient body composition data from any racial-ethnic group other than non-Hispanic whites.

The present body composition estimates were derived from prediction equations, and they are subject to estimation errors. Comparisons of these findings across racial-ethnic groups should be judged accordingly. The standard deviations for the means for TBW, FFM, TBF and %BF approximate the normal range for these variables in the population. This range is reasonably constant from one age group to the next within racial-ethnic groups. However, the standard deviations reported are calculated for estimated not measured values and therefore may underestimate the true variability in the data.

Body composition changes in the population

One observation from these mean distributions is the high level of %BF among non-Hispanic black and Mexican-American females compared with non-Hispanic white females. The TBF and %BF means from NHANES III data are consistent with the previously reported high prevalence of overweight[1,2] and shifts in the BMI distribution observed between NHANES II and NHANES III.[38] However, it is not appropriate to determine the prevalence of obesity from these mean estimates for TBF and %BF in the absence of definite cut-off criteria.[37]

These mean reference values are not an indication of an ideal or desirable level of FFM, TBW, TBF or %BF, and should be used cautiously as comparative reference data. The mean BMI for adult men (BMI = 26.6) and women (BMI = 26.5)[1] currently exceeds the recommended BMI threshold for healthy weight (BMI < 25.0).[39] Similarly, the mean %BF for adult men and women exceeds the threshold of %BF values that indicate obesity at a BMI > 30.0 in men (%BF > 25%) and women (%BF > 39%),[37] beginning at age 50–59 y in non-Hispanic white and black men, at age 30–39 y in Mexican-American men and at age 40–49 y in non-Hispanic black and Mexican-American women. The highest mean estimate for %BF in non-Hispanic white women was 37.3% at ages 50–59 y.

One new aspect of these data is the availability of TBW means. Prior to the present investigation, only small sets of TBW reference data were available[31] and most of these databases have limited application to the general US population. These TBW means provide a general reference for the US population by sex, age and race-ethnicity at the time the NHANES III was conducted (1988–1994).

The FFM means provide a limited reference to assist in determining the degree of sarcopenia or muscle loss among the elderly.[10] Low muscle mass is a major contributor to the loss of functional ability and health.[40] One limitation in defining or in establishing a diagnosis of sarcopenia has been the absence of a sex-, age- and racial-ethnic-specific FFM reference.[10] The present findings provide national estimates as a reference to compare with results from other studies of body composition, particularly FFM, in the elderly and persons with weight-related chronic disease.

Study limitations

These reported body composition estimates are not based on criterion measures. The mean estimates were calculated from predicted values from the bioelectrical impedance Res values and stature in NHANES III. The Valhalla Res values were translated into their RJL equivalents (see Appendix), and then TBW and FFM were predicted through regression equations. In the conversion sample, there was a very small consistent difference between RJL and Valhalla Res measures of 2.5 ohms for males and 9.6 ohms for females (Appendix, Figure 1). The high r^2 values for these conversions are identical to previously reported correlations for Res between Valhalla and RJL impedance analyzers.[44] Others have reported larger systematic differences between Valhalla and RJL analyzers for Res values[45] than were noted in the present conversions. However, the present systematic differences in Res between Valhalla and RJL impedance analyzers for males and females are less than the reported variation in repeated measures of Res using a single impedance machine.[46–48]

In the prediction equations, TBW was estimated from isotope dilution, and FFM was estimated with a multicompartment model based on densitometry, TBW and bone mineral content from dual-energy X-ray absorptiometry using pooled data from large convenience samples from multiple study centers.[22] TBF and %BF were then estimated from FFM and weight. In each of these steps, validity errors can be potentially introduced.

The reported mean body composition values are estimates about which there is variation as a function of the several methods and samples used. The magnitude of this variation is difficult to quantify, but is assumed to be equivalent to the pure errors from the cross validation of the prediction equations.[22] Pure errors for the TBW and FFM equations are ~4 l or kg for males and ~3 l or kg for females. Cross-validation results indicated that the equations applied in this study slightly over-predict TBW by ~0.7 and 0.6 l and FFM by ~0.3 and 0.6 kg for males and females, respectively. The equations used to predict TBW tend to underestimate TBW in black males (~2 l) and females (~1.4 l) and overestimate TBW in white males (~0.5 l) and females (~0.3 l). The FFM equations tend to underestimate FFM in black males (~2.1 kg) and females (~1.6 kg) and overestimate FFM in white males (~0.4 kg) and females (~0.3 kg). These estimates may be acceptable for comparisons within racial-ethnic groups, but should be used cautiously in comparisons across racial-ethnic groups.

There are other possible limitations. BIA prediction equations have limitations similar to those of skinfold prediction equations including large standard errors of the estimates and population specificity.[41] The BIA prediction equations were applied to Mexican-American participants in NHANES III but were neither derived nor validated independently on samples of Mexican-Americans so the validity of these equations for this group is unknown. There were also a few non-Hispanic blacks available in the samples used to develop the prediction equations resulting in potential bias for estimates among this group. Also, the performance of the prediction equations when applied to the NHANES III data could not be independently verified.

Conclusion

These mean body composition estimates (Tables 4–7 and Figures 1–4) are the first provided for the US population. NHANES III did not have criterion body composition measures, but the availability of 50 kHz BIA data allowed the estimation of TBW, FFM, TBF and %BF using externally derived equations based on isotope dilution for TBW and multicomponent models for FFM. These prediction equations for TBW and FFM[22] can be applied to other population groups in the US, and the calculated TBW, FFM, TBF or %BF values compared with the mean estimates presented in this report.

The findings in this report conform to the many existing relationships of body composition with age and sex. What is new, is the availability of these mean estimates for TBW, FFM, TBF and %BF along with their corresponding distributions at specific age categories and the availability of these data for the three racial-ethnic groups in the NHANES III. These means and standard deviations provide a picture of specific aspects of body composition that could only be inferred from the NHANES III BMI data. The newest information from the present analysis is the estimates for mean TBW, FFM, TBF and %BF for Mexican-American males and females. These limited data have not been available in the past.

Measured values for TBW, FFM, TBF and %BF determined by DXA, hydrostatic weighing, or data collected using other reference body composition methods in other studies can be compared with the means reported for the NHANES III sample. Systematic differences among body composition methods and the between-method limits of agreement are approximately 2.0 kg for FFM and 3–5% for %BF,[27,42] and should be considered when interpreting the data or making inferences.

This study presents descriptive summary distributions for body composition estimates derived from the 1988–1994 NHANES III. In the future, improved estimates of FFM and TBF may become available. The present descriptive data should be regarded as interim results and should be applied and referenced with an awareness of the identified potential caveats.

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Appendix

Conversion of NHANES III BIA values

The NHANES III BIA data were obtained with a Valhalla impedance analyzer. Before applying the TBW and FFM prediction equations to these data, the Valhalla Res value for each NHANES III subject was converted to an equivalent RJL Res value using equations developed from a separate, independent sample. Res data collected at the same visit between the right wrist and ankle using a Valhalla 1990B and an RJL 101 BIA instrument were available from 197 male and 235 female participants, 12–65 y of age in the Fels Longitudinal Study.[43] These Fels, RJL Res values were regressed on corresponding Fels Valhalla Res values separately for each sex.

The BIA Res conversion equations are as follows for males and females:

For males: RJL Res = 2.5 + 0.98 Val Res; $r^2 = 0.996$, RMSE = 5.0 ohms
For females: RJL Res = 9.6 + 0.96 Val Res; $r^2 = 0.993$, RMSE = 5.3 ohms

Variance estimation

The means presented in this report are based on a complex sample design, and techniques that account for this design were used to estimate the standard errors of these means (ie the square root of their variance). Variance estimates based on the complex sample design are different from and generally larger than those obtained under the assumption of simple random sampling. The design effect (Deff) measures the influence of the complex sample upon the variance and is defined as the ratio of the complex samples variance, Var_{CS}, to the variance based on a simple random sample of the same size (ie the weighted simple random sample estimate of the variance), Var_{SRS}:

$$\mathrm{Deff} = \frac{\mathrm{Var}_{CS}}{\mathrm{Var}_{SRS}} \tag{1}$$

Because of the wide variability of the design effect across age groups within gender and race-ethnicity, the application of an average design effect stabilizes estimates of standard errors of the mean.[49] More specifically:

- Each of the six race/ethnic (re = 1, 2, 3) and gender (g = 1, 2) specific subgroups was partitioned into seven subgroups.
- Design effects for each of these seven subgroups were estimated for reth and gth group:

$$\mathrm{DEFF(BIA)}_{re,g,a} \quad a = 1, \ldots, 7$$

- A mean design effect across the seven age groups was calculated:

$$\bar{\bar{\mathrm{D}}}\bar{\mathrm{E}}\overline{\mathrm{FF}}(\mathrm{BIA})_{re,g,a} = \frac{1}{7}\sum_{a=1}^{7}\mathrm{DEFF(BIA)}_{re,g,a} \tag{2}$$

- The complex sample standard error of the mean BIA for the reth race/ethnic, gth gender and ath subdomain $\mathrm{sem(BIA)}_{re,g,a,CS}$ was estimated by multiplying the weighted simple random estimate of the standard error of the mean for that domain $\mathrm{s.e.m.(BIA)}_{re,g,a,SRS}$ by the square root of the corresponding race/ethnic and gender specific mean design effect given in equation (2)

$$\mathrm{s.e.m.(BIA)}_{re,g,a,CS} = \mathrm{s.e.m.(BIA)}_{re,g,a,SRS}\sqrt{\bar{\bar{\mathrm{D}}}\bar{\mathrm{E}}\overline{\mathrm{FF}}(\mathrm{BIA})_{re,g}} \tag{3}$$

SUDAAN, a statistical software package that incorporates the sample weights and accounts for the complex sample design through Taylor Series linearization was used to estimate the design effects.[26] The complex sample standard deviation, σ_{CS}, was estimated by adding the square of the complex sample estimate of the standard error of the mean given in equation (3) to the square of the simple random sample estimate of the standard deviation $\hat{\sigma}_{SRS}{}^2$ and taking the square root of this sum:

$$\hat{\sigma}_{CS} = \sqrt{\hat{\sigma}^2_{SRS} + [\mathrm{s.e.m.(BIA)}]^2_{RE,G,CS}} \tag{4}$$

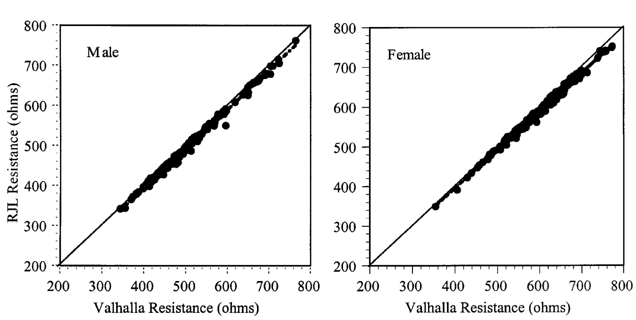

Figure A 1 Plots of RJL resistance values against Valhalla resistance values in males and females.